Journal of Forestry Research (2011) 22(1): 111−115
DOI 10.1007/s11676-011-0135-2

ORIGINAL PAPER

Durability characteristics of cement-bonded particleboards manufactured from maize stalk residue

Ajaye Babatunde

Received: 2010-04-01; Accepted: 2010-08-10

Abstract: Cement-bonded particleboards of 6 mm in thickness were manufactured using maize stalk (*Zea mays*) particles of uniform sizes at three levels of board density and additive concentrations respectively. The bending strength and dimensional properties were assessed. Increase in board density and additive concentration caused increase in Modulus of rupture (MOR), Modulus of elasticity (MOE), and decrease in Thickness swelling (TS) and Water absorption (WA). The MOR, MOE and TS of the boards were significantly affected by board density except for WA, but additive concentration affected all the boards' properties examined at $p \geq 0.05$. Strong and dimensional stable cement-bonded boards could be manufactured from maize stalk particles with Portland cement as the binder after hot water treatment. Although the dimensional stability and mechanical strength properties of the boards were affected by the board density and additive concentration, the study revealed that cement-bonded particleboards could be manufactured from maize stalk (*Zea mays*) particles. However, the increase in board density and additive concentration could cause the increase in MOR and MOE, and cause the decrease in TS and WA of boards.

Keywords: raw materials; strength properties; analysis of variance; dimensional changes; particleboards

Introduction

At present, the major raw materials for cement-bonded particleboards consist mainly of wood, cement and water with or without a catalyst (Ajayi 2008; Papadopoulos 2008). The acceptability of these products stems from the availability and widespread distribution of the raw materials locally. However, the scarcity of the economically preferred wood species, over-exploitation of natural and plantation hardwood species, lack of effective utilization of wood resources due to huge wastes incurred in wood processing industries and encroachment into the free and reserved forests from unlicensed timber exploiters call for concerted efforts by the researchers and wood scientists to initiate common solutions to the rapid depletion of wood resources in Nigeria and world wide. Finding alternative sources of raw materials for wood industries to manufacture panel products would meet the demand of wood products for construction works in perpetuity.

Agricultural residues as substitute for wood in the manufacture of value-added panel products become paramount as boards produced could be used as alternative to the timber, which will further increase the industrial and economic base of the National Development (Erakhrumen et al. 2008; Ajayi 2003c). Proper management of agricultural residues could generate employment opportunities, increase the earning power of the farmers and provide other services, which may be the best option on reducing encroachment, exploitation pressure on the reserving the tropical forests and reducing the destruction of forests biodiversity as means of mitigating world climate change. However, the cement-bonded boards could be served as alternative to timber products in the furniture industry and construction works (Aladenola et al 2008), bringing about significant improvement in wood products supply, better management of wood resources on sustained yield basis and the reduction in environmental degradation due to over exploitation of the tropical forests.

Lots of researches went into the use of wood as raw materials for cement bonded boards (Chittenden et al. 1993; Ajayi 2000) and agriculture residues (Ajayi 2003a and 2003b; Simantupang et al. 1993). The use of agricultural residues for manufacture of panel products is relatively low compared with the use of wood. These residues are regarded as of no vital importance, and could not be regarded as having huge economic loss and waste of resources, but wealth could be created if judiciously used for value-added products manufacture. The use of these raw materi-

The online version is available at http://www.springerlink.com

Ajaye Babatunde (✉)
Department of Forestry and Wood Technology, Federal University of Technology, P.M.B 704 Akure, Ondo State, Nigeria.
E-mail: babatundeajayi2000@yahoo.com, Phone: 08034540627

Responsible editor: Yu Lei

als for boards' production would initiate a revolutionized research activities in sourcing and conversion of other agricultural byproducts to valuable products.

The new products will promote increase in continuous establishment of agricultural produce such as maize, which will increase food production. The high cost of thermosetting resins, machinery and heat energy requirement hindered the development of resin-bonded particleboards in developing countries. The development of cement-bonded boards from maize-stalk will be served as genuine alternative, as the raw materials can be secured locally at cheaper rate and in a large quantity. Cement-bonded boards are considered to be highly denser compared with resin-bonded boards. They also provide resistance to termite attack, fire and any other degrading agents (Ajayi 2003c; Dinwoodie et al. 1991).

Maize (*zea mays*), which belongs to the grass family, is cultivated twice annually and grows to height of 1 m–3 m. The bole is straight and solid with nodes and internodes. The diameter at the nodes is greater than internodes. The internodes are bigger and short at the stump, longer towards the middle and thinner towards the top of the bole. The leaves and corn cob grow on the nodes. The maize cob is harvested green for 13–14 weeks after planting and leaving the stem to decay on the floor of the farm. In the year of 2002, 2003 and 2004, the total maize harvest in Nigeria was 6 698 000 t, 7 185 000 t and 7 908 800 t respectively (Central Bank of Nigeria 2004). The continuous increase in harvest was as a result of high investment in agricultural production through the provision of soft loans with low interest. The use of these byproducts for value added panels production will serve as genuine route out of poverty. The objective of this study was to investigate the suitability of maize stalk for cement-bonded particleboards production and to assess the bending strength and dimensional stability of the boards manufacture.

Materials and method

The maize stalk (*Zea mays*) used in this study was harvested in green condition from the Research Farm of the Federal University of Technology, Akure, Ondo State, Nigeria. The maize stalks were cut into billets at the points corresponding to the length between two nodes. The nodes were cut off and the spongy-like substance inside the core of the stalk was removed. Matchet was used to reduce the billets into flakes and transported to the Forestry Research Institute of Nigeria, Ibadan, where the maize stalks were reduced to particles by the use of hammer mill.

The particles were sieved with 2 mm wire mesh to obtain homogenous particles for the study. The particles were dried in the open air for two weeks to cause the degradation of the extractives. Then, the particles were then poured inside an aluminum bath containing hot water at 80°C and the treatment lasted for one hour. This was done in order to remove possible inhibitory chemical substances present in them, which may be likely poison, inhibit the setting and curing of cement binder. After hot water treatment, the leachate containing water soluble extractives and sugars was drained and washed in cold water for 10 min. The particles were air dried and kept inside a controlled laboratory environment at the moisture content of 12% approximately for two weeks prior to board manufacture.

Production variables used in board manufacture were as follows: Board density was 1 050 $kg \cdot m^{-3}$, 1 100 $kg \cdot m^{-3}$ and 1 150 $kg \cdot m^{-3}$. Additive concentration was 1.5%, 2.5% and 3.5%. Constant variables were as follows: Mixing ratio was 3.0:1.0. Board thickness was 6 mm. Moisture content of particles was 12% approximately. Pressing pressure was 1.23 $N \cdot mm^{-2}$.

The quantity of maize-stalk particles required for the fabrication of each board were weighed out and poured inside a mixing plastic bowl. The quantity of chemical additive (calcium chloride) for each board was dissolved in the quantity of water needed and mixed together. This was in turn poured on the maize stalk aggregates inside the mixer and mixed together to wet and saturate the particles. The amount of Portland cement for each board was slowly added and thoroughly mixed until a well-blended homogenous particles-water-cement-chemical additive paste free of particles/cement lumps was achieved.

A wooden mould of 350 mm × 350 mm square was placed on a metallic caul plate that was covered with polythene sheet, and the furnish was formed manually into a uniform mat inside the mould. After mat formation, plywood caul plate was placed on top and pre-pressed to reduce thickness of the board formed. Thereafter, the plywood plate was removed and replaced with polythene sheet and metallic plate. The mat was transferred to a cold press and pressed under a pressing pressure of 1.23 $N \cdot mm^{-2}$ to a targeted thickness of 6 mm for 24 h. Similar method was used to produce all the other boards for this study. Later boards were demolded for post-curing. Firstly, boards were kept inside properly sealed polythene bags for 28 days for progressive setting and curing of cement to occur. After this the edges of the boards were trimmed to avoid edge effects on the test specimens. Test specimens were conditioned in controlled laboratory environment at 20°C and relative humidity of 65±2% for 21 days.

The bending strength test was assessed by using test specimen of 194 mm×50 mm×board thickness on tensiometer testing machine. Specimens were separately supported equally on metal rollers at two points of 17 mm away from the two ends of each test specimen. Load was applied at the center perpendicular to the face and over the entire width of the board's specimens by using a rounded metal bar. Modulus of rupture (MOR) and modulus of elasticity (MOE) were strength properties examined. Thickness swelling (TS) and water absorption (WA) properties of boards were assessed by using the test specimen of 152 mm×152 mm, and they were immersed in the cold water for 48 hours. All tests were carried out according to the procedure described in ASTM D (1978). The statistical design for the study was 3×3 factorial experiments in completely randomized design which gave nine experimental boards. Analysis of variance was carried out to determine the significant effect of the factors of production on boards' properties. Duncan multiple comparison test method was used to determine the significance of observed differences in sample means at 0.05 levels of significance.

Results and discussion

Modulus of rupture and modulus of elasticity

Table 1 presents the mean values for modulus of rupture (MOR) and modulus of elasticity (MOE). They ranged from 1.11 N·mm^{-2} to 4.48 N·mm^{-2} for MOR and from 1 050.96 N·mm^{-2} to 3 719.22 N·mm^{-2} for MOE. MOR mean values were similar to those reported by Badejo (1999) as 3.28–10.46 N·mm^{-2} and Fuwape (1995) as 4.0–15.0 N·mm^{-2}. The result also shows that the board density and additive concentration are related to the MOR and MOE values as they are directly influenced by each level of combination. The increase in board density and additive concentration caused the increase in MOR and MOE values (Fig. 1 and 2). This, therefore, made it possible to produce the strongest experimental boards at the highest levels of board density (1 150 kg·m^{-3}) and additive concentration (3.5%). However, heavier, stronger and stiffer boards could be manufactured by progressively increasing the board density (Ajayi 2000; Blakenhorn et al. 1994) and additive concentration (Ajayi 2000; Badejo 1999; Fuwape 1995). The influence of board density becomes increasingly significant as the proportion of wood (Ajayi 2008; Badejo 2005) and that of calcium chloride increased (Ajayi 2000; Badejo 1999; Fuwape 1995). For example, strongest boards were produced at the highest levels of the combined variables.

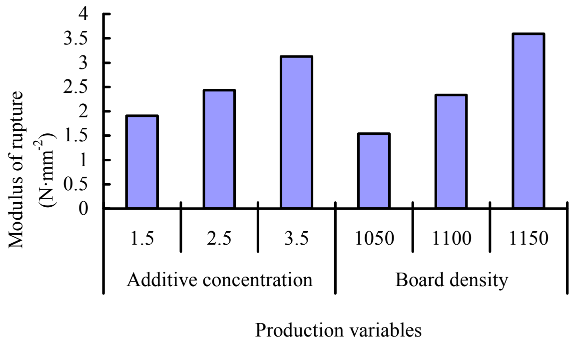

Fig. 1 Effect of production variables on modulus of rupture

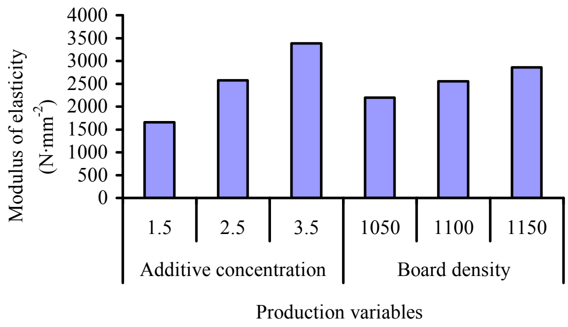

Fig. 2 Effect of production variables on modulus of elasticity

Table 1. The average values obtained for MOR, MOE, TS and WA of maize stalk-based particleboards.

Board Density (kg·m^{-3})	Additive Concentration (%)	MOR (N·mm^{-2})	MOE (N·mm^{-2})	TS (%)	WA (%)
1050	1.5	1.11±0.14	1050.96±71.83	8.43±0.83	33.67±5.97
1100	1.5	1.49±0.28	1749.28±187.79	7.43±0.69	32.75±3.41
1150	1.5	3.14±0.08	2161.50±74.25	7.09±0.29	32.15±5.94
1050	2.5	1.48±0.48	2489.27±156.96	6.19±0.30	31.58±2.25
1100	2.5	2.66±0.12	2531.47±152.78	5.70±0.30	30.76±0.51
1150	2.5	3.16±0.33	2695.60±539.87	5.64±0.27	29.89±3.07
1050	3.5	2.03±0.46	3056.40±71.52	5.28±0.38	27.30±2.39
1100	3.5	2.86±0.28	3380.87±160.12	5.21±0.29	25.69±2.04
1150	3.5	4.48±0.73	3719.22±446.76	4.92±0.27	25.50±2.56

The number before "±" denotes mean values of three replicate, and the number after "±" denotes standard error.

Greater compaction of boards was achieved as a result of increased the number of bonds and interfaces contact areas between the particles. The possible effect of remnant inhibitory substances was reduced as the quantity of calcium chloride increased which accelerated the setting of cement binder and retarded the activities of sugars on cement setting. Also, it could be deduced that heavy and dense nature of boards withstanding the load applied to break the boards was as a result of significant effect of the factors of production. Table 2 shows that significant differences exist in the MOR and MOE, as board density and additive concentration had significant influence on them. The two factors interaction has no significant effect on MOR and MOE at 0.05 level significance. Table 3 shows significant difference in the MOR and MOE of boards between 1 050 kg·m^{-3} and 1 100 kg·m^{-3}, 1 100 kg·m^{-3} and 1 150 kg·m^{-3}; 1 150 kg·m^{-3} and 1 050 kg·m^{-3} and also with additive concentration between 1.5% and 2.5%, 2.5% and 3.5%, 3.5% and 1.5%, respectively.

Table 2. Analysis of variance of MOR, MOE, TS and WA of cement-bonded boards.

Sources of variation	*df*	*F* value			
		MOR	MOE	TS	WA
Board density (BD)	2	20.937*	73.880*	75.497*	8.324*
Additive Concentration (AC)	2	62.266*	11.209*	6.699*	0.516*
BD & AC	4	2.650ns	1.907ns	1.284ns	0.013
Error	18				
Total	27				

"*" denotes significant (p<0.05), and "ns" denotes not significant (p>0.05).

Table 3. Results of multiple comparisons for board density and additive concentration

Factors	Levels	Modulus of rupture ($N\cdot mm^{-2}$)	Modulus of elasticity ($N\cdot mm^{-2}$)	Thickness swelling (%)	Water absorption (%)
Board	1050	1.54^a	2198.88^a	6.63^a	30.85^a
density	1100	2.34^b	2553.87^b	6.11^a	29.73^a
($kg\cdot m^{-3}$)	1150	3.60^c	2918.12^c	5.88^b	29.18^a
Addictive	1.5	1.76^a	1590.46^a	7.64^a	32.86^a
concentra-	2.5	2.51^b	2584.45^b	5.84^b	30.74^b
tion (%)	3.5	3.12^c	3385.50^c	5.14^c	26.17^b

Values with the same superscript are not significantly different at $p> 0.05$ and vice-versa. Multiple comparison was done using Duncan multiple range test.

Thickness swelling and water absorption

Table 1 contains the summary of the average values obtained for thickness swelling (TS) and water absorption (WA) after 48 h immersion in the cold water. These values ranged from 4.92% to 8.43% for TS, 25.50% to 33.67% for WA. The values indicate that the increase in board density and additive concentration was responsible to the decrease in TS and WA as shown in Fig. 3 and 4. The lowest TS and WA values observed at the highest board density (1 150 $kg\cdot m^{-3}$) and additive concentration (3.5%) levels are 4.92% and 25.50%, respectively. As a result, more dimensionally stable boards were produced at these levels as they showed relatively high resistance to TS and WA. Therefore, board density and additive concentration were found to have remarkable effect on the TS and WA of the manufactured boards. It is deduced that when the board is exposed to wet conditions, the compression stress is released, which causes the boards springback, structural deformation, breakdown of bonds, fragility of boards and reduction in board's stability (Ajayi 1993; Hiziroglu et al. 1993). However, the swelling of boards caused by the release of compressive stress is not reversible except the increase in the level of water–intake (Ajayi 2000).

The irreversibility of compression stress is associated with irreversibility of board's stability and loss of bonds (Ajayi 2000 and 2003a). The downward trend of the values of TS and WA (Fig. 3 and 4) was due to the gradual increase in the quantity of the two production variables (board density and calcium chloride) used in boards manufacture. The reduction of the releases in compression stresses at the highest board density showed that highly dense boards resisted the springback forces (Ajayi 2000; Ajayi 2003b; Ajayi 2005; Fuwape et al. 1993). The increase in the concentration of calcium chloride had similar effects, in that boards produced at the highest level, had effectively retard the effect of remnants inhibitory substances in the particles and also increase the exothermic reaction of the cement by accelerating the setting and subsequent curing of the boards (Ajayi 2000; Ajayi 2003b; Simatupang et al. 1990; Saka et al. 1992). Analysis of variance of Table 2 shows that the effect of board density and additive concentration on TS and WA is significant at $p\geq0.05$ level. The interaction between the two variables has significant effect on TS only and not on WA.

Table 3 shows the result of the Duncan multiple range test, it reveals significant difference in TS with board density between 1 050 $kg\cdot m^{-3}$ and 1 100 $kg\cdot m^{-3}$, 1 100 $kg\cdot m^{-3}$ and 1 150 $kg\cdot m^{-3}$, 1 050 $kg\cdot m^{-3}$ and 1 150 $kg\cdot m^{-3}$, and with the additive concentration between 1.5% and 2.5%, 2.5% and 3.5%, 1.5% and 3.5%. In case of WA, significant difference does not exist between the levels of board density, but additive concentration had significant difference only between 1.5% and 2.5%, 1.5% and 3.5% respectively. It further shows the significant effect of each level of board density and additive concentration on dimensional movement of boards under investigation.

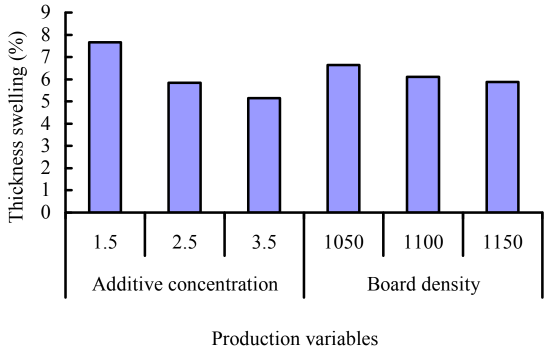

Fig. 3 Effects of production variables on thickness swelling

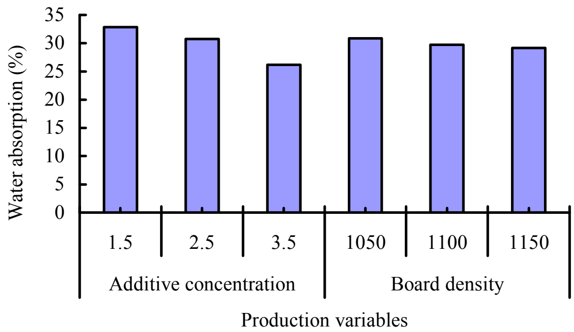

Fig. 4 Effect of production variables on water absorption

Conclusion

From the results of this present study, maize stalk (*Zea mays*) particles provided suitable raw material for the production of cement-bonded particleboards. Boards produced showed resistance to compression stress releases as a result of contact with water, indicating that they were structurally stable. The dimensional stability and mechanical strength properties of the boards were affected by the board density and additive concentration. However, the increase in board density and additive concentration could be attributed to the increase in MOR, MOE and the decrease in TS and WA of boards. Boards produced at the highest levels of the two variables are strongest and most stable than other boards. The follow-up test established the level of significant effect of board density and additive concentration on MOR,

MOE, TS and WA of cement-bonded boards.

Reference

Ajayi B. 2000. Strength and dimensional stability of cement-bonded flakeboard produced from *Gmelina arborea* and *Leucaena leucocephala* Unpublished Ph.D. Thesis, Federal University of Technology, Department of Forestry and Wood Technology, Akure, Nigeria. 176.

Ajayi B. 1993. A review of international standard methodology of accelerated aging test in particleboard. *The Nigerian Journal of Forestry*, **23**(2): 71–74.

Ajayi B, Badejo SOO. 2005. Effects of board density on Bending Strength and internal bond of cement-bonded Flakeboards. *Journal of Tropical Forest Science*, **17**(2): 228–234.

Ajayi B. 2003. Assessment of the dimensional stability of cement–bonded particleboard from post-harvest banana stem residues and sawdust. World Forestry Congress, at Quebec City, Canada. Vol. A: 157.

Ajayi B. 2003. Investigation of the dimensional stability of cement-bonded composite boards fabricated from Coffee Husks, *The Nigerian Journal of Forestry*, **33**(2): 88–93.

Ajayi B. 2003. Short term performance of cement-bonded hardwood flake boards. *Journal of Sustainable Tropical Agricultural Research*, **8**: 16–19.

Ajayi B. 2008. The dimensional stability and strength properties of inorganic-bonded particleboards made from eupatorium odorata particles**.** 62nd Forest Products Society Conference. St Louis, Missouri, USA. Book of Biographies and Abstracts. pp 27.

American Society for Testing and Materials. 1978. "Standard Methods of Evaluating the Properties of Wood based fibre and particle Panel Materials" ASTM Desig. D1037–1078. Philadelphia Pennsylvania.

Badejo SOO. 1999. Influence of process variables on properties of cement-bonded particleboards from mixed tropical hardwoods. PhD Thesis, Federal University of Technology, Department of Forestry and Wood Technology, Akure, Nigeria, 255pp.

Central Bank of Nigeria. 2004. Statistical Bulletin. Vol.15. Central bank of Nigeria, Abuja, Nigeria. 392p.

Dinwoodie JM, Paxton BH. 1991. The long-term performance of cement-bonded wood particleboard. In: Moslemi, A.A. (Ed), Proc. 2nd Inter. Inorganic Bonded Wood and Fiber Composite Materials Conference. Forest Prod. Res. Soc. Madison W/S. pp 45–54.

Erakhrumen AA, Areghan SE, Ogunleye MB, Larinde SL, Odeyale OO. 2008 Selected physico-mechanical properties of cementbonded particleboard made from pine (*Pinus caribaea* M.) sawdust-coir (*Cocos nucifera* L.) mixture. *Scientific Research and Essay*, **3**(5): 197–203.

Fuwape JA. 1995. The effect of cement-wood ratio on the strength properties of cement-bonded particleboard from spruce. *Journal of Tropical Forest Products*, **1**: 49–58.

Fuwape JA, Oyagade AO. 1993. Bending strength and dimensional stability of tropical wood-cement particleboard. *Bioresource Technology*, **44**: 77–79.

Hiziroglu S, Suchsland O. 1993. Linear expansion and surface stability of particleboard. *Forest products journal*, **43**(40): 31–34.

Aladenola OO, Ajayi AE, Olufayo AA, B Ajayi. 2008. Assessment of *Gmelina arborea* sawdust-cement-bonded rainwater storage tank. *Environmentalist*, **28**: 123–127.

Papadopoulos AN. 2008. Natural durability and performance of hornbeam cement bonded particleboard *Maderas. Ciencia y tecnología*, **10**(2): 93–98.

Saka S, Sasaki M, Tanahashi M. 1992. Wood-inorganic composite prepared by sol-gel. processing 1: Wood-Inorganic Composites with Porous Structure, *Mokuzai Gakkaishi*, **38**(11): 1043–1049.

Simatupang MH, Rahim S, Jinsik S. 1993. The Cabon-dioxide injection method. An Environmentally Friendly Process to Fabricate Cement-bonded Boards From Oil Palm Trunk. Conf. On Forestry and Forest. Prod. Res. 1993. Kuala Lumpur, Malaysia. Pp 117–127.

Simatupang MH, Geimer RL. 1990. Inorganic binder for wood composites: feasibility and limitations. In: *Proceedings of Wood Adhesive Symposium*, *Forest Product Resources Society*, pp: 169–176.